Visibility and Aerosol Measurement by Diode-Laser Random-Modulation CW Lidar

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1. Introduction. In recent years, the diode laser (DL) has shown a large development in the lasing power, the mode quality, and reliability. Lidar systems using DL were reported in the application to the slant visibility measurement[1)] and the ceilometer[2)]. However, the DL power is usually limited by the catastrophic optical damage at the cavity surface. Therefore, the peak power of the pulsed operation is within the range of only a few orders of magnitude larger than the cw power, and single mode operation is difficult and the excellent features of the DL are not sufficiently utilized in pulsed operation. In this situation, random-modulation cw (RM-CW) lidar[3)] is suitable for the efficient use of the small DL power. We designed a portable DL RM-CW lidar with the detection ability of the aerosol profile up to 1 km in distance, reported the construction at the 12th ILRC[4)], and published the preliminary results[5)]. Here we report the further development of the DL RM-CW lidar and its application to the field use.

2. System. The principle of the RM-CW lidar is based on the δ-function-like feature of the autocorrelation of pseudo-random code (we use M-sequence in this system), and the details are described in Ref. 3).

The DL RM-CW lidar was constructed as a compact, portable and easy-handling system. It consists of three parts: lidar head, processor, and personal computer. The whole system can be carried by a small van and operated by one person. The details of the purposes of construction and the original specifications are described in Ref. 5). The present specification is shown in Table 1. The items of improvement are

1) the power-up of the DL from 15 to 36 mW
2) improvement of the receiving optics (smaller aberration with larger aperture)
3) change of photomultiplier to the one with a large dynamic range

3. Outdoor measurements. Different from the laboratory measurement, outdoor operation has the severe conditions such as the variation of the power supply voltage and the large changes in environmental temperature and humidity. Sometimes the temperature of DL is necessary to be kept in a certain range for stable operation in single-mode. Otherwise a ghost may appear in lidar data. After the above improvement, we obtained a nighttime aerosol profile over a 1 km distance. In the following, we introduce some examples of the outdoor measurements.

(1) Visibility. Visibility is the important meteorological parameter for the aviation safety as well as an index of comfortableness. Especially slant visibility is an important parameter for the landing of the airplanes. Visibility is inversely proportional to a distance averaged value of the extinction coefficient of the light passing through the atmosphere. Therefore the accurate profile of aerosol is not required. Werner et al[1] monitored the visibility at Munich Airport for a long time using a pulsed DL lidar system. We derived the visibility based on the slope method and compared it with the data from a transmissometer (Meisei TZE-3T) set on the same site. An example for fast visibility change is shown in Fig. 1. The lidar shows smaller value than the transmissometer due to the inhomogeneous distribution of the aerosol. For spatially varied aerosol distribution, the exact visibility value should be obtained by resolving the lidar equation according to the Klett method[6].

(2) Aerosol vertical profile. Range-corrected aerosol profile (linear plot) with the elevation angle of 10 deg is shown in Fig. 2. This was taken automatically with the time interval of 20 min. The integration time was 80 sec. The cross-over function becomes 1 at about 200 m. In a case of DL, the beam divergence is very small so that a small size of the laser beam cross section is small enough to use a mirror for bending the direction of the laser. Therefore if we set a mirror along the ground surface so that the crossover function is unity beyond the mirror, we obtain the vertical aerosol profile from the ground surface.

(3) Cloud movement. When the thickness of the cloud is not thick enough, the structure of the cloud is easily measured by the lidar. In Fig. 3, the rapid change of the cloud is shown. The data are taken every 30 sec with integration time of 10 sec. A cloud is shown at the height of 1000 m. The signal near the ground is the aerosol.

4. Summary.

We report some examples of the DL RM-CW lidar measurement. They demonstrate the ability for the measurement of the visibility, vertical aerosol profile, and the cloud ceiling height. Although the data shown here were all measured at nighttime, the daytime measurement is of course possible. For that purpose, accurate control of the laser frequency to the center frequency of a narrow band filter is required. Now a new system with a frequency control is under construction.

References

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3) N. Takeuchi etal: Random modulation cw lidar, Appl. Optics 22, 1382(1983).
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Table 1. Specifications of a DL RM-CW Lidar

LASER: GaAlAs-DL(Sharp)	
Wavelength	780 nm
Output	36 mW
Driving current	160 mA(bias) + 100 mA(mod)
Operating Temp.	-5 ~ 10°C
Beam Divergence	<0.1 mrad (after collimation)
MODULATION: M-seq. random code	
Clock time	60 ns
Number of elements	4095 ($=2^{12}-1$)
Period	240 μsec
Range resolution	9 m
RECEIVING OPTICS	
Telescope	Schmidt-Cassegrain (reflection)
Aperture	150 mm
Focal length	1500 mm (eff.)
FOV	0.5 ~ 3.0 mrad
Opt. filter bandwidth	1.2 nm
DETECTOR: PMT	Hamamatsu R928
Quantum efficiency	0.1
Amplific. factor	1×10^7
SIGNAL PROCESSOR	
ADC	3 bit (clock time 60 ns)
Accumulation	up to 2^{16}

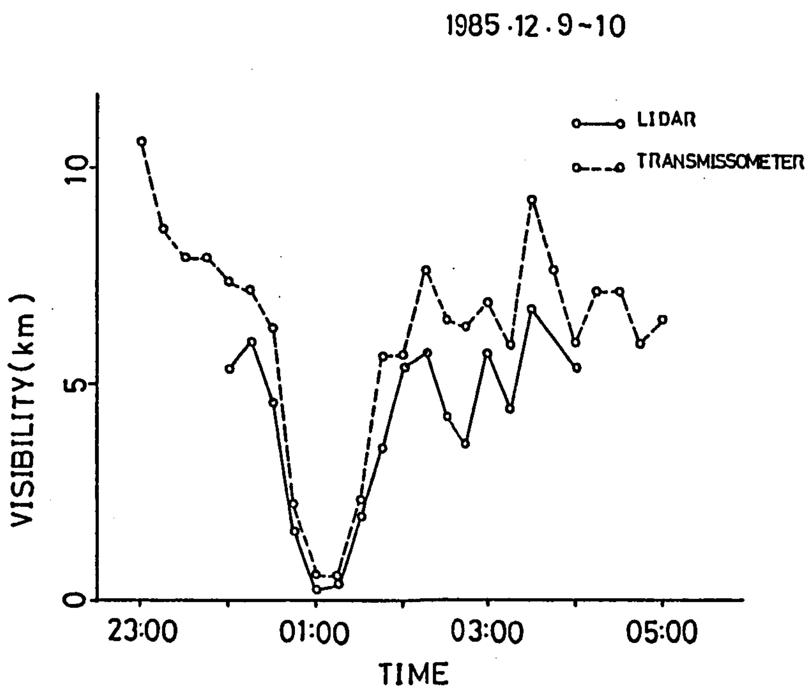

Fig. 1 Comparison of visibility data between a DL RM-CW lidar and a transmissometer.

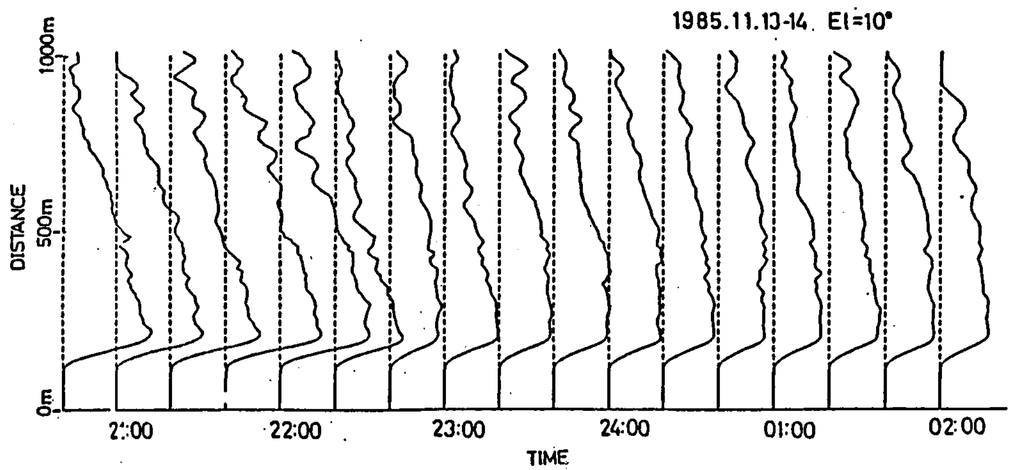

Fig. 2 Sequential measurement of aerosol profile. Elevation angle: 10 deg, integration time 80 sec.

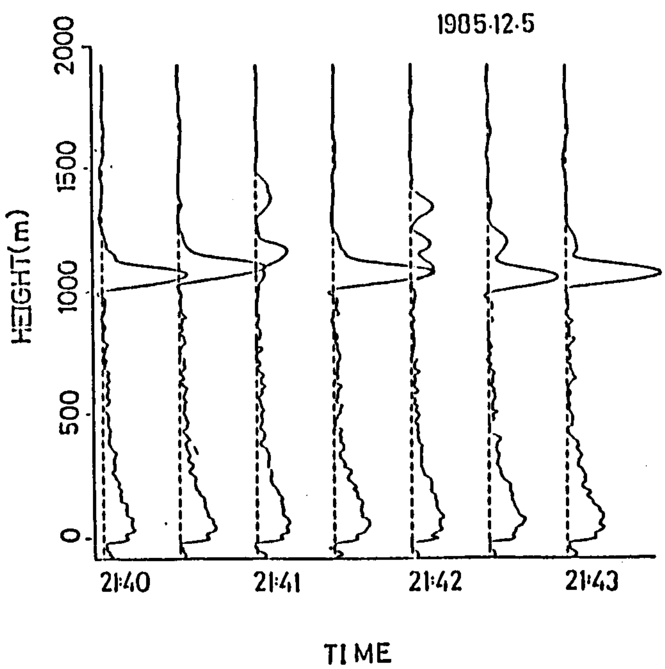

Fig. 3 Temporal variation of the cloud thickness. Accumulation time: 5 sec, no range correction.